Prospects for Affordable Access to Space for Small Payloads, 2003-2012

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Abstract. Affordable access to space has been one of the key issues in the history of space exploration. It is a particularly critical issue for small payloads, where the cost of launch can run many times more than the cost of the payload itself, making many projects financially infeasible. This paper surveys the vehicles in service today as well as those announced or under development in the next decade that can address the small payload market. This analysis includes the estimated launch costs, launch rates, and capacities of the vehicles, as well as the likelihood that vehicles under development will actually enter service. Three capacity models show that the number of launch opportunities on small launch vehicles range from 212 to 471 over the next decade, depending on the availability of a number of vehicles currently under development. The introduction of partially-reusable launch vehicle systems like RASCAL and Xerus offer the best prospects for providing low-cost launch services for small satellites.

Introduction

Arguably the greatest challenge for small satellite projects has been obtaining launch services at affordable prices. While spacecraft can be built relatively inexpensively, often using student or volunteer labor, no such cost savings are available in the launch services sector. This has forced spacecraft developers to seek a number of alternatives for launches, each with its own disadvantages. These alternatives range from launching secondary payloads on larger launch vehicles, with corresponding schedule and orbit restrictions; to purchasing launch services on former Russian ICBMs, which can present export control issues for developers in some countries, notably the United States. Multimanifesting several small satellites on a larger vehicle is also a common option, although this requires both a degree of scheduled flexibility as well as the ability to find sufficient payloads with whom to share the launch.[1]

At the same time the launch market itself has been in considerable turmoil. This turmoil stems from a sharp drop in launch demand in the last few years, triggered in large part by the failure of a number of companies that deployed or planned to deploy constellations of small communications satellites in low Earth orbit (LEO). In 1998 the Federal Aviation Administration forecast there would be 1,202 satellites launched commercially by 403 vehicles into non-geosynchronous orbit (NGSO) from 1998 through 2010.[2] By 2003 the FAA had revised those projections to 80 satellites and 51 launches from 2003 through 2012.[3] This sharp decline has led to a shakeout in the launch vehicle market, with a number of existing or proposed vehicles either going dormant or being cancelled. At the same time, though, there have been a number of new vehicles announced in the last few years that are designed to serve the small launch market.

To shed light on this situation, this paper examines the launch vehicle capacity—the total number of launches selected vehicles could support—for the small satellite market. This paper studies the availability of launch opportunities for small satellites using small launch vehicles: those vehicles that would permit the launch of a small satellite as either the primary payload or as a part of a group of small satellites that comprise the primary payload of the launch vehicle. Three models will illustrate the size of the launch market in both best- and worst-case scenarios.

Criteria

This analysis focused on launch vehicles that fall in the "small" launch vehicle category as defined by the Federal Aviation Administration (FAA): vehicles capable of placing no more than 2,268 kilograms (5,000 pounds) into LEO. This limit is designed to exclude larger vehicles that are unlikely to launch small satellites as primary payloads. (There are some exceptions to this limit, which are mentioned in the Vehicles Considered section.) While launch opportunities exist for small satellites on larger vehicles, these opportunities are almost exclusively as secondary payloads and as such fall outside the scope of this study.

Each vehicle included in the study was judged using several criteria designed to measure its affordability, reliability, and availability. These criteria are summarized below:

Availability

Availability measures the estimated number of launches each year that vehicle can provide. For existing vehicles this number is based on the number of launches the vehicle has performed in recent years, selecting the peak number unless there is evidence to suggest that this peak is unsustainable. For vehicles yet to enter service, the launch providers' estimates of the number of launches the vehicle can perform, coupled with other analyses, are used instead.

LEO Capacity

This metric measures the maximum payload size the vehicle can place into LEO. In most cases the most generous capacity value (usually associated with the due east launch into an orbit between 185 and 300 kilometers altitude) is used here, although this value will vary depending on the exact orbit desired. In some cases the vehicle's capacity for polar or Sun-synchronous orbits is used when no other data are available or when the vehicle is only used for such payloads.

Success Percentage

This is the percentage of launches a vehicle has made (as of mid-June 2003) deemed successful. In most cases the relatively small number of launches renders this measure of limited value: of the vehicles included in this study only two—the Cosmos and the Pegasus XL—have flown more than ten times.

Launch Price

This is the estimated cost of one launch of the vehicle. These values are based on open-source data, including print and online media reports. Launch price data has become difficult to obtain in the last few years as demand for launch services decreased considerably. Anecdotal observations suggest that launch prices have dropped during this time as launch service providers competed for a limited number of customers. Thus, the fidelity of these data may not be as high as desired, but represent the best numbers publicly available today.

Launch Price per 100 kg

This value is derived by taking the launch price, dividing by the LEO capacity, and then multiplying by 100. It is designed to provide a first-order estimate of the cost to launch a 100-kilogram payload—a typical small satellite—on the vehicle. This is not necessarily the price a customer would pay to fly the payload, since there may be additional costs to the customer not included in the launch price. However, those additional costs may be partially or completely mitigated by decreases in launch prices in recent years not captured in the launch prices used in this analysis, as discussed above.

Probability of Entering Service

This is a subjective metric of the likelihood that the vehicle will actually enter service during the 10-year timeframe of this analysis. "Existing" means the vehicle has already performed at least one launch. "High" is used for those vehicles currently under development deemed very likely to enter service, either because they are in the final stages of development or have strong backing from a company or government agency. "Medium" is assigned to vehicles proposed or under development that could

Table 1: Launch Vehicles Included in This Study

Vehicle Name	Intro. Year	Avail. (launch/yr)	LEO Cap. (kg)	Launches		Success %	Launch Price (M)	Launch Price per 100kg (M)	Prob.
				Success	Total				
Air Launch	2006*	5	3500		0	N/A	$21.5	$0.61	Low
Angara 1.1	2004*	1	2000		0	N/A	N/A	N/A	Medium
Athena 2	1998	1	1990	2	3	67%	$24.0	$1.21	Existing
Cosmos	1967	3	1400	410	429	96%	$13.0	$0.93	Existing
Dnepr	1999	2	4400	3	3	100%	$15.0	$0.34	Existing
Eagle	TBD	2	580		0	N/A	$9.0	$1.55	Low
Eaglet	TBD	2	1360		0	N/A	$13.0	$0.96	Low
Falcon	2003	4	570		0	N/A	$6.0	$1.05	High
J 1	1996	1	900	1	1	100%	$45.0	$5.00	Existing
M 5	1997	1	1800	3	4	75%	$40.0	$2.22	Existing
Minotaur	1999	2	640	2	2	100%	$12.5	$1.95	Existing
Pegasus XL	1994	5	445	20	23	87%	$22.5	$5.06	Existing
RASCAL	2006	12	100		0	N/A	$0.8	$0.75	Medium
Rockot	1994	2	1800	4	4	100%	$15.0	$0.83	Existing
Shavit 1	1988	1	225	4	5	80%	$12.5	$5.56	Existing
Shtil	1998	1	430	1	1	100%	$0.3	$0.07	Existing
Sprite Mini-Lift	2006	4	315		0	N/A	$2.0	$0.63	Medium
START	1995	1	645	0	1	0%	$10.5	$1.63	Existing
START 1	1993	1	632	5	5	100%	$9.0	$1.42	Existing
Strela	2003	1	1700		0	N/A	$10.5	$0.62	High
Taurus 1	1994	1	1450	5	6	83%	$19.0	$1.31	Existing
Vega	2006	2	1500		0	N/A	$20.0	$1.33	High
VLS	1997	1	380	0	2	0%	$6.5	$1.71	Existing
Volna	2001	1	120	1	2	50%	$0.3	$0.25	Existing
Xerus	2007*	12	10		0	N/A	$0.5	$5.00	Medium

* estimated

enter service in the next decade, but must overcome significant technical or financial barriers. "Low" is used for those vehicle concepts that have been announced to be ready in the next decade but appear unlikely to enter service during that time, if ever. Low-probability vehicles are not included in the capacity analyses later in this paper.

Vehicles Considered

As noted earlier, this paper limits its scope primarily to small launch vehicles either in used today or planned for introduction in the next decade. The properties of these vehicles, using the criteria described in the preceding section, are summarized in Table 1. Descriptions of the vehicles follow:

Air Launch

Air Launch is a joint venture by several Russian aerospace companies, including the Polyot Aviation Company and Rocket Space Corporation Energia, to develop a system for launching small and medium payloads from aircraft. The system would use a two-stage Polyot launch vehicle carried aloft and deployed from an Antonov An-124 cargo aircraft. The vehicle would be able to place up to 3,500 kg into LEO, and thus would be considered a medium launch vehicle by the FAA. However, it is included here because the venture has focused on the vehicle's use to deploy several smaller LEO satellites[4]. While Air Launch announced in 2000 it planned its first flights in mid-2003, there have been no indications of progress towards that first flight. In June 2003 RSC Energia announced it was withdrawing from the venture because it claimed the project's partners "have behaved themselves incorrectly."[5] This lack of progress and loss of a major shareholder leads to the conclusion that the vehicle is unlikely to enter service in the foreseeable future, and is thus rated "low" in this analysis.

Angara 1.1

The Angara 1.1 is the smallest member of the new Angara family of launch vehicles under development by Russia's Khrunichev State Research and Production Space Center. The Angara will be able to place 2000 kg into LEO when launched from Plesetsk Cosmodrome in northern Russia. The launch price of the Angara 1.1 has not been announced. The vehicle will be marketed to commercial customers by International Launch Services (ILS), the US-Russian joint venture that also markets the Atlas and Proton boosters commercially, although it is believed that ILS will focus on the larger versions of the Angara designed to launch geosynchronous orbit communications satellites.[6]

Athena 2

The Athena 2 was a small launch vehicle developed by Lockheed Martin to serve the small launch market. The vehicle could place up to 1,990 kg into low-Earth orbit,[7] but its high launch cost—estimated to be nearly \$25 million a launch—hindered its use by most customers. No future Athena launches have been manifested, although the vehicle is still officially available.[8] While the Athena 2 is included here in this analysis as an existing vehicle, it is not included in the capacity analyses later in this paper.

Cosmos

The Cosmos (or Kosmos) 3M is the most experienced small booster included in this analysis, having conducted 429 launches (410 successfully) since its introduction in the mid-1960s.[9] This vehicle can place up to 1,400 kg into LEO for less than \$15 million, according to the most-current pricing data available. There is some question regarding the availability of this vehicle in the future: Isakowitz *et al.* noted in 1999 that vehicle production had halted in 1995 and that there were only 15 unassigned vehicles remaining, but that production could be restarted.[10] Since the vehicle continues to be marketed, this analysis assumes that the Cosmos will continue to be available through the 10-year forecast timeframe at a modest flight rate of three launches a year.

Dnepr

The Dnepr is a decommissioned SS-18 “Satan” ICBM converted into use as a launch vehicle. The vehicle is capable of placing up to 4,500 kg into LEO, putting it into the medium launch vehicle class, but is included in this analysis because to date it has been primarily used to launch clusters of small satellites. The Dnepr was to be phased out in 2007 in accordance with the START 2 arms control treaty between the United States and Russia, but a modification to the treaty signed in 2002 eliminated the deadline for the destruction of the SS-18 missiles. Kosmotras International Space Company, the Russian company that markets the Dnepr commercially, expects the vehicle to remain in service well into the next decade.[11]

Eaglet and Eagle

Eaglet and Eagle are two small launch vehicles proposed by E’Prime Aerospace, a Florida company. The two vehicles would be based on solid motors developed for the Peacekeeper ICBM: Eaglet could place 580 kg into LEO for $8-10 million while Eagle could loft 1,360 kg for $12-14 million; both would be launched from the Kennedy Space Center.[12] E’Prime Aerospace is also planning larger versions of these vehicles. The company has, however, shown little progress in recent years converting these plans into actual vehicles, and has yet to raise the financing needed to proceed with vehicle development. Therefore, this analysis considers that these vehicles have only a low probability of entering service during the timeframe of this paper, and thus are not included in the capacity analysis later in this paper.

Falcon

Space Exploration Technologies (SpaceX), a startup company based in El Segundo, California, is developing the Falcon launch vehicle to serve small payloads for relatively low costs. The Falcon is a two-stage vehicle (whose first stage is designed to be reused) that can place approximately one-half ton into LEO for $6 million. (Use of strap-on liquid-propellant boosters could increase the vehicle’s capacity to 1,820 kg.) Although the company started operations in mid-2002, the company has made significant progress, test-firing the vehicle’s first-stage engine. As of mid-June 2003 the company planned to perform its first launch on December 17, 2003, from Vandenberg Air Force Base, California.[13] Because of the progress the company has made, and the existence of a firm source of funding from company founder Elon Musk, this vehicle is considered highly likely to enter service.

J 1

The J 1 was developed by the Japanese space agency NASDA to launch small payloads. The vehicle could launch 900 kg into LEO, but at a prohibitively high cost, estimated to be up to $45 million. The vehicle has flown only once, in 1996, and while a second launch was planned, NASDA plans to phase out the vehicle in favor of a medium-class vehicle, Galaxy Express, currently under development.[14] Because of these factors the J 1 is not included in the capacity analysis in this paper.

M 5

The M 5 (or Mu 5) vehicle is used by the Japanese space agency ISAS to launch small payloads. The vehicle can place 1,800 kg into LEO for an estimated cost of $40 million. The M 5, introduced in 1997, has flown four times, including one launch failure in 2000.[15]

Minotaur

The Minotaur is based on both the Minuteman ICBM and Pegasus launch vehicle: the first two stages of the four-stage Minotaur are the lower two stages of a Minuteman and the upper two are the second and third stages of a Pegasus XL. Combined, the Minotaur can place 640 kg into LEO for an estimated price of $12.5 million. Minotaur launches are restricted to payloads approved by the US Air Force. The vehicle has flown only twice, both in 2000, but in 2003 Orbital Sciences Corporation won an Air Force contract to provide three additional Minotaur launches this decade.[16]

Pegasus XL

The Pegasus XL and its predecessor, the Pegasus (no longer in service), have provided launch services for small payloads since 1990. The Pegasus XL can place up to 445 kg into LEO; its air-launched nature and ability to use a number of launch ranges allows it to place orbits into almost any inclination.[17] While the price of a Pegasus XL launch has in the past been quoted at $12-15 million, more recent accounts put the cost in the $20-25 million range.[18] This cost has led to limited commercial use of the vehicle, with NASA now the primary customer.

RASCAL

The Defense Advanced Research Projects Agency (DARPA) started work in 2002 on a program called Responsive Access, Small Cargo, Affordable Launch (RASCAL) to prove low-cost space access for small satellites. The goal of RASCAL is to develop a launch system using a small rocket deployed at high altitude by a supersonic aircraft that can place payloads of up to 125 kg into LEO for $750,000.[19] DARPA let a $21.9-million Phase 2 contract to Space Launch Corporation in March 2003 to continue development of the program, with the goal of two flight demonstrations in fiscal year 2006.[20] Because this program is in the early development phase, but has backing from a government agency, this analysis concludes that RASCAL (or a RASCAL-derived system) has a medium probability of entering service during the next decade.

Rockot

The Rockot is a decommissioned Russian SS-19 ICBM converted for use as a launch vehicle. The vehicle can place 1,800 kg into LEO for $13-15 million a flight, and has performed four flights as of mid-June 2003, as well as two suborbital test flights in the early 1990s. The vehicle is marketed commercially by Eurockot, a German-Russian joint venture, who has signed up a number of government and commercial customers.[21]

Shavit 1

The Shavit 1 is an Israeli booster capable of placing 225 kg into LEO (the booster places its payloads into a retrograde orbit because it is launched westward over the Mediterranean from Israel.) The Shavit has flown only five times (including one failure) since its 1988 introduction, at an estimated cost of $10-15 million a flight. This vehicle has been used exclusively to date for Israeli military payloads, although there have been attempts in the past to develop commercial versions of the vehicle for launch from other locations, including Cape Canaveral.[22]

Shtil

The Shtil is a Russian submarine-launched SS-N-23 ballistic missile converted into use as a satellite launcher. It has been used to date only once, in 1998. The vehicle can place 430 kilograms into LEO for as little as $100,000 to $300,000, in part because launches are designed to be part of scheduled naval exercises.[23]

Sprite Mini-Lift

Sprite Mini-Lift is the smallest orbiter launcher of the Scorpius family of launch vehicles being developed by Microcosm. The Sprite Mini-Lift would be based on the smaller SR-S and SR-M suborbital vehicles being developed by Microcosm; the company has also proposed developing larger vehicles based on the same technology. The vehicle could place 315 kg into LEO for $2 million a launch. Microcosm plans to conduct the first development flight of Sprite Mini-Lift in mid-2005 with production flights to follow in early 2006.[24]

START and START 1

START and START 1 are converted Russian SS-15 ICBMs; the five-stage START is identical to the four-stage START 1 except that it uses the START 1's second stage as its second and third stages. The two vehicles can each place 600-650 kg into LEO for $9-10.5 million each. The START has flown only once, in 1995; that launch was a failure. START 1 has flown five times, all successfully.[25][26]

Strela

Strela, like Rockot, is based on the SS-19 ICBM, but is marketed by NPO Mashinostroyeniya rather than Eurockot. Unlike Rockot, Strela does not use the Breeze upper stage; it also uses a different payload fairing. It can place 1,700 kg into LEO for an estimated price of $10.5 million. The first Strela launch is scheduled for mid-2003; it will carry a test payload.[27]

Taurus

The Taurus launch vehicle, developed by Orbital Sciences Corporation, uses a Castor 120 first stage and three upper stages derived from a Pegasus. (A Taurus variant replaces the Castor 120 with the first stage of a Peacekeeper ICBM.) It can place up to 1,450 kg into LEO for an estimated price of $18-20 million. The vehicle has performed six launches to date; the last, in September 2001, was a failure.[28][29]

Vega

Vega is a small launch vehicle being developed by the European Space Agency. It will be capable if placing 1,500 kg into a low Earth polar orbit when launched from Kourou, French Guiana.[30] The vehicle is expected to enter service in 2006; no launch price has been formally announced, but is expected to be on the order of $20 million a flight.[31] This analysis considers it highly likely the vehicle will enter service this decade, since ESA issued development contracts earlier this year.[32]

VLS

The Velculo Lançador de Satellites (VLS) is a small Brazilian launch vehicle developed in the 1990s. It is capable of placing 380 kg in LEO for $8 million when launched from Brazil's Alcantara launch facility, near the Equator. The vehicle's first two flights, in 1997 and 1999, both ended in failure; a third launch attempt is scheduled for the latter half of 2003.[33]

Volna

The Volna is a Russian submarine-launched SS-N-18 ballistic missile. Like the Shtil, the Volna offers very low-cost launch services because of its use as part of naval exercises: as little as $300,000 to place 120 kg into LEO. The Volna has performed two suborbital launches, one of which failed. Its first orbital flight is scheduled for the latter half of 2003 when it will launch the Cosmos 1 solar sail spacecraft.[34]

Xerus

XCOR Aerospace of Mojave, California, is developing the Xerus suborbital reusable launch vehicle for a variety of markets, including microsatellite launches. The Xerus spaceplane would take off from a runway under rocket power and fly to an altitude of 100 km, at which point it would release a small expendable upper stage.[35] This launch system could place 10 kg into LEO for approximately $500,000.[36] No firm introduction date has been announced.

Capacity Models

Using the criteria and launch vehicles described above, we can now the capacity of the launch vehicle market at various price points, that is, the estimated number of launches that are possible for a given range of launch prices. This is not the same as the number of launches that will take place, but rather an estimate of the maximum number that could take place, given the capabilities and past records of the various vehicles considered.

Three different approaches are taken for the capacity model. The "baseline" model uses those vehicles currently available (with two exceptions), as well as those vehicles deemed having a high probability of entering service. The "robust" model adds to the baseline model those vehicles with a medium probability of entering service. The "restricted" model subtracts from the baseline model those vehicles that have see little, if any, utilization in recent years, and/or limited to a small range of government payloads.

Unless otherwise stated, vehicles are assumed to be available at the same capacity throughout the ten-year timeframe of the model. For new vehicles, the model assumes that the vehicle will perform one flight the year of its introduction and half of its listed capacity the following year before ramping up to full capacity in future years.

Baseline model

The baseline model includes all the vehicles listed in Table 1 as "existing", with the exception of the Athena 2 and J 1, which appear unlikely to launch again. The model also includes the three high-probability vehicles from Table 1, the Falcon, Strela, and Vega.

The results, broken out by launch cost per 100 kg of payload, are listed in Table 2. The total capacity of this model is 277 launches, with vehicles costing $2 million or less per 100 kg payload accounting for three-quarters of the market. Most of the rest is accounted for by the Pegasus XL and its high ($5.06 million per 100 kg) launch costs.

Table 2: Baseline Model Launch Capacity by Launch Cost

Launch Costs per 100kg	Launches	Percentage
Greater than $2 mil	70	25.3%
$1-2 mil	107	38.6%
Less than $1 mil	100	36.1%
Total	**277**	**100.0%**

According to Table 2, 100 of the 277 launch opportunities possible in the next decade will come from vehicles that can offer launches for under $1 million per 100 kg of payload. However, as Table 3 illustrates, most of these launch opportunities are unsuitable for single small satellites: only 20 of the 100 are offered on vehicles with capacities below 500 kg. The majority are offered on vehicles with LEO capacities of 1000 to 2000 kg, meaning that a small satellite seeking launch services on these vehicles would either have to multimanifest with other small payloads or fly as a secondary payload.

Table 3: Baseline Model Low-Cost Launches by Vehicle Capacity

Vehicle Capacity	Number of Launches
Less than 500 kg	20
500-999 kg	0
1000-1999 kg	60
More than 2000 kg	20
TOTAL	**100**

Robust model

The robust model is the same as the baseline model but includes the four additional medium-probability vehicles listed in Table 1: Angara 1.1, RASCAL, Sprite Mini-Lift, and Xerus. For RASCAL and Xerus we assume fairly conservative launch rates: while these reusable launch systems are designed to fly relatively frequently, on the order of at least once a week, we assume here they will actually launch payloads on average once a month.

The results, broken out by launch cost per 100 kg of payload, are shown in Table 4. Under the robust model the total number of launch opportunities is 471, a 70% increase over the baseline model. The number of launches priced at less than $1 million per 100 kg of payload nearly doubles in the robust model, to 190. The number of launches priced at over $2 million per 100 kg of payload also increases significantly, to 125, although this is an artifact of the introduction of the Xerus: the vehicle is priced at $5 million per 100 kg of payload, but can only carry 10 kg.

Table 4: Robust Model Launch Capacity by Launch Cost

Launch Costs per 100kg	Launches	Percentage
Greater than $2 mil	125	29.0%
$1-2 mil	107	24.8%
Less than $1 mil	190	44.1%
Unknown	9	2.1%
Total	**431**	**100.0%**

The robust model offers a more encouraging outlook for small satellite developers seeking affordable launch services, as shown in Table 5. Not only have the number of launch opportunities for launches under $1 million per 100 kg of payload increased from from 100 to 190, that increase took place exclusively among vehicles with a LEO capacity of under 500 kg, notably RASCAL and Sprite Mini-Lift. In addition, Xerus offers an affordable alternative for very small payloads, with a total launch cost of only $500,000 for 10-kg spacecraft.

Table 5: Robust Model Low-Cost Launches by Vehicle Capacity

Vehicle Capacity	Number of Launches
Less than 500 kg	110
500-999 kg	0
1000-1999 kg	60
More than 2000 kg	20
TOTAL	**190**

Restricted model

The restricted model is based on the baseline model, but with the removal of several existing vehicles: M 5, Shavit 1, Shtil, START, and VLS. These vehicles are removed from the model because they either have not been launched in recent years and/or are limited to a very narrow range of payloads (Japanese scientific spacecraft for the M 5, Israeli reconnaissance spacecraft for the Shavit) that preclude their use by the wider small satellite community. In addition, the Cosmos booster is removed from the model in 2008, citing the limited availability concerns noted earlier in this paper.

The results, broken out by launch cost per 100 kg payload, are shown in Table 6. The restricted model offers only 212 launch opportunities between 2003 and 2012, down 23% from the baseline model. Of those, 75, or 35%, would come from vehicles that offer a launch cost of $1 million or less per 100 kg of payload. Table 7 shows that only 10 of those 75 launch opportunities—that is, only those launches by the Volna—use vehicles with a total LEO payload of less than 500 kg.

Table 6: Restricted Model Launch Capacity by Launch Cost

Launch Costs per 100kg	Launches	Percentage
Greater than $2 mil	50	23.6%
$1-2 mil	87	41.0%
Less than $1 mil	75	35.4%
Total	**212**	**100.0%**

Table 7: Restricted Model Low-Cost Launches by Vehicle Capacity

Vehicle Capacity	Number of Launches
Less than 500 kg	10
500-999 kg	0
1000-1999 kg	45
More than 2000 kg	20
TOTAL	**75**

Conclusions

The three capacity models described in this paper show that the prospects for affordable launch opportunities for small satellites are very dependent on the development of a number of proposed low-cost launch vehicles. The number of affordable launch opportunities for small satellites on small vehicles is limited without the introduction of several vehicles currently proposed or under development, including RASCAL, Sprite Mini-Lift, and Xerus. Yet the developers of these vehicles face a critical hurdle: they must demonstrate to sources of funding in the public and private sectors that there is sufficient demand for their launch services to warrant their development. If small satellite developers want the low-cost launch opportunities these vehicles could offer, they must demonstrate to the vehicle developers and their funding sources that the demand for launch services exists.

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